# IRIS Observations of the Transition Region above Sunspots

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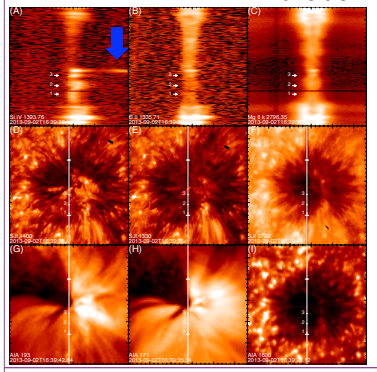
## Abstract

We present results from IRIS observation of the transition region above sunspots. The major findings can be summarized as following: (1) Many subarcsec bright dots are present in SJI 1330Å and 1400Å images obtained in high-cadence observations. These bright dots are observed in the penumbrae of all sunspots we inspected, and are occasionally present in the umbrae and light bridges of some sunspots. Some bright dots show apparent movement with speeds of 10-40 km/s (either outward or inward). The lifetime of these penumbral dots is mostly less than 1 min. The most obvious spectral features are the absence of the O IV 1401 line and the broadened Si IV line profiles. Some bright dots appear to be located at the footpoints of coronal loops. Many of them are likely generated by impulsive reconnection in the TR and chromosphere. (2) Strongly nonlinear sunspot oscillations can be clearly identified in the slit jaw images of 2796Å, 1400Å and 1330Å, and spectra of the bright Mg II, C II and Si IV lines. The maximum intensity slightly lags the maximum blue shift in Si iv, whereas the intensity enhancement slightly precedes the maximum blue shift in Mg ii. We find a positive correlation between the maximum velocity and deceleration, consistent with numerical simulations of upward propagating magneto-acoustic shock waves. We also demonstrate that the strongly nonlinear line width oscillation, reported both previously and here, is spurious. (3) Persistent supersonic downflows at TR temperatures are clearly detected in many sunspots. Many of them appear to be associated with sunspot plumes. (4) The normally reserved C II and Mg II line profiles are almost Gaussian in the sunspot umbra, suggesting a greatly reduced opacity in the sunspot atmosphere.

## Transition region above sunspots



Sunspot spectra completely different from plage spectra:

1. C II & Mg II lines not reversed, suggesting greatly reduced opacity in sunspots. Similar features have also been found in Lyman lines by Tian et al. (2009, A&A, 505, 307).
2. Sunspot TR can be very bright. These bright features in the umbra are the TR footpoints of coronal loops or sunspot plumes.
3. Supersonic downflows with speeds of ~100 km/s (e.g, indicated by the blue arrow) are often clearly identified at some of these bright locations.
4. Oscillations are clearly present in not only the spectral lines, but also the SJI images. But no obvious oscillation for the supersonic downflows.

Fig. 1. A-C: IRIS spectra along the slit. The wavelength range (horizontal dimension) is about 1.2 Å for the FUV lines and 2.4 Å for Mg II. D-I: Images of IRIS/SJI and SDO/AIA. The field of view has a size of 47"x47".

## Subarcsec bright dots in sunspots' transition region

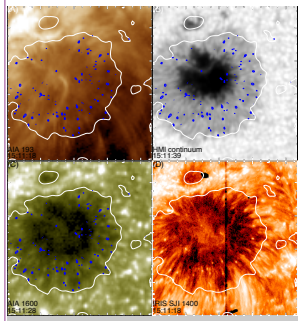


Fig. 2. Context images. The blue contours mark locations of some bright dots in sunspots.

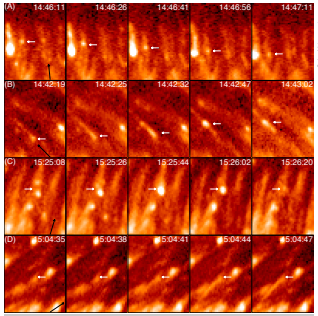


Fig. 3. (A)/(B) An outward/inward moving dot. (C) Two dots merge. (D) Initiation of a ~400km/s jet from a dot.

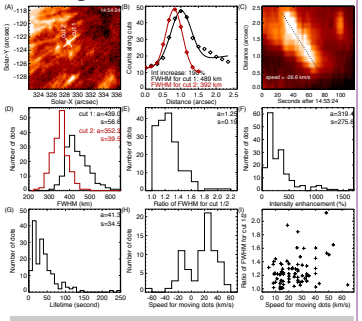


Fig. 4. Quantifying some penumbral bright dots. Cut 1/2: length/width.

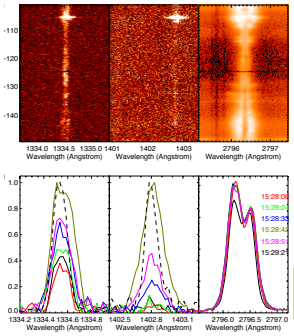


Fig. 5. Typical spectra of a bright dot. Upper: Spectra along the slit at 15:28:42. Lower: Line profiles at 6 different times.

Results are summarized in:
Tian et al. ApJL, 2014, 790, L29
Tian et al. ApJ, 2014, 786, 137

Many rapidly evolving subarcsec dot-like features in all sunspots:

1. Mainly in penumbrae, but also occasionally in umbrae and light bridges.
2. Typical size: 0.5". Often slightly elongated, with the two dimensions being 300-600 km and 250-450 km, respectively.
3. Sometimes at the edge of penumbral filaments/loop legs. Long sides often nearly parallel to the filamentary structures but sometimes clearly deviate from the radial direction.
4. Lifetimes: mostly less than one minute.
5. About half of them show apparent movement with speeds of 10-40 km/s in the radial direction, either inward or outward.
6. Spectral signatures: intensity & line width enhanced.
7. Possible generation mechanism: Impulsive small-scale energy release events (nanoflares?) at the transition region footpoints of magnetic loops?

## Sunspot oscillations in the transition region

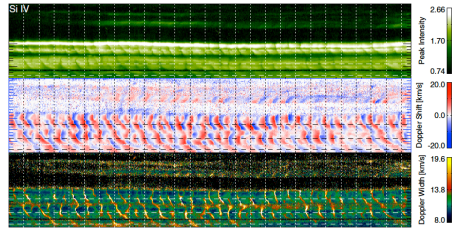


Fig. 6 Temporal evolution of the SGF peak intensity, Doppler shift, and line width along the slit marked in Fig. 1. Interval between two vertical lines: 3 min.

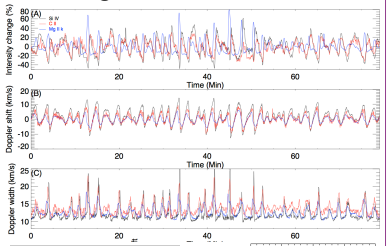


Fig. 7 Temporal evolution of the SGF peak intensity, Doppler shift, and line width at the slit location 3 marked in Fig.1.

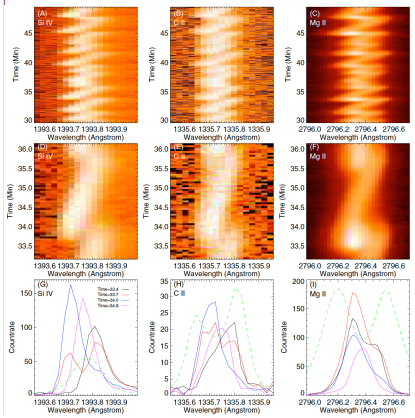


Fig. 8: (A)–(F) Wavelength–time plots for location 3. (G)–(I) Line profiles at several times.

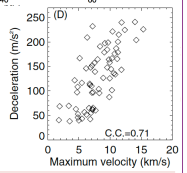


Fig.9: Scatter plots of the relationship between shock parameters.

Upward propagating shock waves:

1. Line core behavior: a rapid excursion to the blue, accompanied by an intensity increase, followed by a linear decrease (both intensity and blue shift) to the red
2. The maximum intensity slightly lags the maximum blueshift for the TR lines. However, the intensity enhancement of Mg II occurs before the maximum blueshift is reached
3. Line width oscillation: superposition of the newly shocked plasma and the back-falling material after the passage of the previous shock in LOS
4. Correlation between maximum velocity and deceleration, consistent with simulations of upward propagating MA shock waves (Hansteen et al. 2006, De Pontieu et al. 2007)